MULTI-AGENT MODEL PROTOTYPE FOR CHILD VEHICLE SAFETY INJURY PREVENTION

Z. KOBTI,* S. RAHAMAN, and R.D. KENT, School of Computer Science,
and A.W. SNOWDON and T. DUNLOP, Faculty of Nursing,
University of Windsor, Ontario, Canada

ABSTRACT

Injury prevention is a growing concern in the health care sector mainly as a result of the mounting health care costs for full patient recovery. In particular, the safety of children's car seats is important to parents, legislative regulators, and automotive manufacturers. Deploying the child restraint mechanism; selecting the correct type of car seat on the basis of the age, height, and weight of the child; and correctly using the seat present a number of challenges for the driver. Driving frequency, distance, and traffic, along with the driver's experience and history, are only some of the factors that can contribute to an accident. We base our model parameters on measures colleted from recent surveys. We build a multi-agent simulation in Repast that mimics the driver's behavior that leads to the selection of a child restraint and the injury outcome after an accident. In this initial iteration of development, we report on the design phase and initial prototype. We define the level of agency and autonomy involved in the system by identifying the roles and attributes of individuals within a social context in a closed yet dynamic environment. We formulate a number of key index indicators, such as driver experience, correctness of child restraint use, accident probability, and the individual injury level following an accident. The prototype is initialized with known survey data and configured with probes to measure the injury outcome and various demographics. The prototype sets the stage for the next iteration, where we will deploy learning mechanisms to enable agents to harness the safety knowledge available in the system and employ it to decrease injury.

Keywords: Agent-based modeling system, vehicle safety, child seats, injury prevention

INTRODUCTION

Injuries due to road crashes are the leading cause of death worldwide for persons aged 0 to 44 years. The World Health Organization (WHO) has investigated the impact of road crashes globally and projects that they will be the third leading cause of death worldwide by the year 2020 (WHO 2004). Although developed countries fare better than undeveloped countries, these injuries remain a significant health issue in countries such as Canada and the United States. In Canada, injuries account for $12 billion of health care spending annually. Globally, 1.2 million deaths are attributed to road crashes — approximately 3,200 deaths per day. One of the major issues in injury prevention research relative to road crashes is the complexity of the factors that influence vehicle safety, particularly for vulnerable populations, such as children.

* *Corresponding author address*: Ziad Kobti, School of Computer Science, University of Windsor, 401 Sunset Avenue, Windsor, Ontario, Canada N9B-3P4; e-mail: kobti@uwindsor.ca.

Traditional approaches to injury prevention research identify multiple factors or variables that influence crash outcomes, often using cross-sectional statistical approaches. However, the multi-dimensional nature of injury outcomes from vehicle collisions requires new and innovative approaches to data analysis in order to fully understand the multi-dimensional nature of injury prevention.

The fundamental characteristics of vehicle safety and injury prevention research encompass an understanding of human behavior and the environment, as well as a number of associated social and economical components. Health researchers teamed with computer scientists from the University of Windsor to embark on developing a virtual model to replicate such an environment. Critical aspects of the model involve human intelligence exhibited in software agents with the ability to act rationally through the use of knowledge and information and in pursuit of a goal. Agents differ in important characteristics by reacting to environmental and socioeconomic variations, as well as by deliberately employing knowledge, reasoning, and even learning to plan to achieve their goal. The collaboration of agents is another critical property in social systems. The dynamic environment provides agents with a nonlinear change over time, presenting agents with a constant need to adapt and learn from their own as well as from others' experiences. The changes are often the result of feedback that the agents receive as a result of ongoing activities. Individual agents tend to organize into groups or hierarchies and form a structured organization, often influencing the underlying system's evolution. Investigators probing these systems often can identify emerging properties arising from the interactions and actions of the individual agents. These attributes together characterize a complex system. A multi-agent simulation consequently acts as a tool in modeling real-world complex systems, in which an agent provides the observer with a first-person's eye view of the world as it unfolds in the simulated world (Kobti 2003).

The purpose of this pilot study is to employ agent modeling as a strategy for examining the interactions of the multiple dimensions of injury outcomes associated with vehicle crashes. The first section presents an overview of the literature related to children vehicle safety, followed by a characterization of agent-based modeling and social systems. The next section provides a detailed methodology for the simulation prototype and finally reports the results of initial testing and model validation strategies.

LITERATURE REVIEW

Research that examines children's safety in vehicles has grown substantially in the past few years. One of the most consistent and alarming findings in the research is that motor vehicle accidents continue to be the leading cause of death and serious injury among children under the age of 14 years (Zaza et al. 2001). In Canada, these collisions result in hundreds of child fatalities annually. Despite the availability of effective safety restraint devices, an additional 15,000 young Canadians are severely injured annually as a result of roadway accidents, (Transport Canada 2003). When child safety restraints are used correctly, the risk of death and/or serious injury can be reduced by as much as 74% (Biagioli 2002; Weber 2002). Many countries are moving toward legislation for child safety seats in response to this growing body of evidence, but legislating increased use alone may not be adequate to protect children from trauma due to vehicle collisions.

Safe Seat Transitions

Continued deaths and injuries to children are occurring partly as a result of vehicle safety practices not being accurately matched to the occupants' body structure. The majority of safety experts agree that height, weight, and age (for infants) are the key determinants in child restraint choice and transition. All child restraint devices and children under the age of 12 should be in the rear seats of vehicles. Initially, infants must ride in a rear-facing seat — until they weigh 22 pounds and until they reach the age of at least one year (O'Day 2001). The second transition requires parents to move their child from the infant seat to the forward-facing seat. Children remain facing forward until they weigh 40 lb and are at least 40 inches tall. The next transition occurs for children who are between 40 and 57 inches tall and weigh between 40 and 80 lb. At this height and weight, children are most safely restrained in a booster seat (Apster et al. 2003; Lee et al. 2003). Unfortunately, with the exception of two Canadian provinces, children over 40 lb can be legally secured by a vehicle seat belt system. Lap and shoulder belts have always been developed and tested for adults; however, they do not offer adequate protection for children weighing less than 80 lb. Most parents do not know that a seat belt offers less than optimal protection for their school-aged child (Rivara et al. 2001). Without knowledge of the importance of safe booster seat use, parents prematurely graduate their children to vehicle seat belts, completely unaware of the risks or falsely believing that they made a correct choice (Simpson et al. 2002). One study suggests that two-thirds of children were inappropriately restrained by seat belts (Ramsey et al. 2000). Similarly, a recent Canadian survey reported that only 28% of school-aged children are restrained in booster seats (Safe Kids Canada 2004). These results call attention to numerous missed opportunities for controlling unnecessary deaths and injuries to children in vehicles.

Consequences of Inappropriate Transition

The risks associated with premature graduation to seat belts by young children have been established in the literature (Winston et al. 2000). Certainly, the most extreme outcome of not using a booster seat is fatalities following collisions. However, inadequately restrained children are also more likely to sustain serious injuries to the head, neck, spine, and abdomen (Winston et al. 2000). Injuries occur because children's small torso and underdeveloped pelvic bones offer a less-than-optimal fit for both shoulder and lap belts (Slatter and Vargish 1998).

In the event of a crash, a shoulder harness positioned somewhere other than over the sternum allows for excessive movement of the head and upper body, commonly associated with negative spinal outcomes, skull fractures, and severe brain injuries (Winston et al. 2000). Similarly, ill-fitting lap belts place undue pressure on the abdomen. Findings from a crash surveillance study (Winston et al. 2000) revealed that only children prematurely restrained in seat belts incurred abdominal injuries. Other lap belt injuries frequently reported in the literature involve the lumbar spine and intestinal tract (Lane 1994). Preventing early seat belt transitioning is an important means of decreasing the prevalence of child deaths and injuries in vehicles. Figure 1 illustrates the percentage of premature seat belt use among children of varying ages as collected from field survey data. The trend reveals that as a child's age increases, drivers are more likely to use a seat belt to restrain the child instead of the appropriate child restraining device.

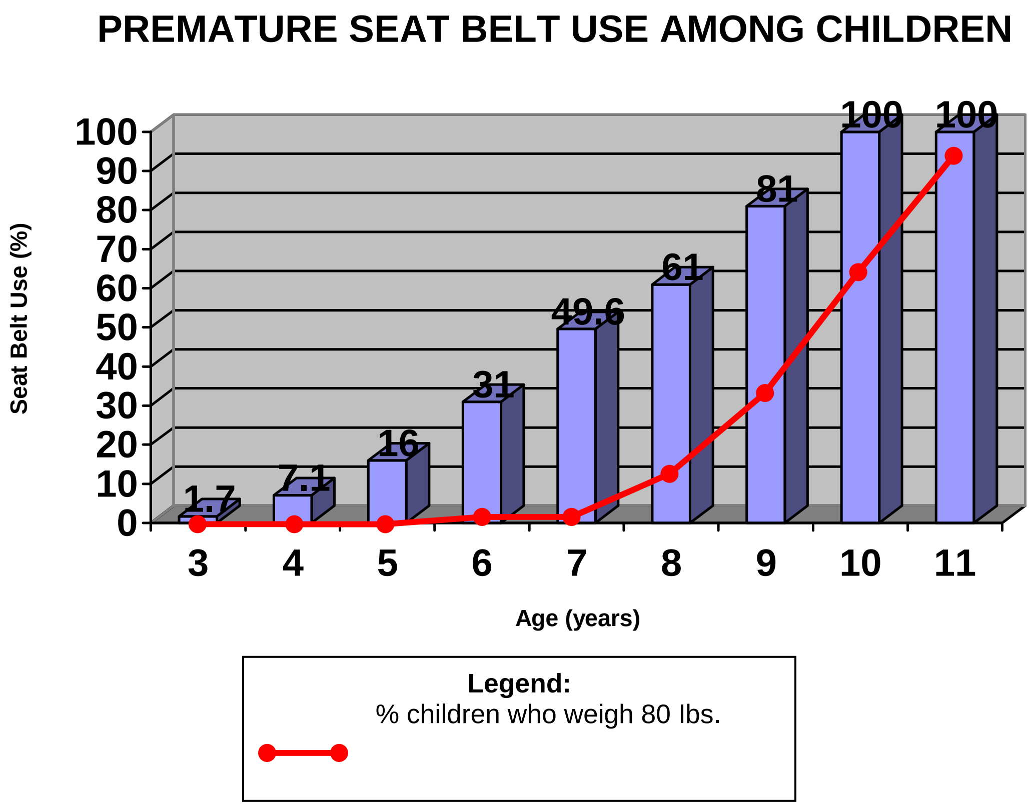

FIGURE 1 Premature seat belt use among children by age

Issues of Use and Misuse

While the majority of parents attempt to use vehicle safety systems to protect their children, misuse and nonuse continue to be significant factors in injury outcome for children traveling in vehicles. Biagioli (2002) reported that more than 80% of safety seats are misused. Correct use requires that the child safety restraint be (1) appropriate for the child's height and weight, (2) accurately installed and positioned in the vehicle, and (3) used every time the child is transported in the vehicle. Progressive patterns of child growth and development pose particular challenges for many parents. Normal physical and cognitive changes throughout phases of the child's life cycle require parents to learn to install and use a variety of vehicle restraints for each stage of their child's growth and development. For example, infants quadruple their weight in the first two years, and children "normally" gain weight steadily, at 4 to 6 lb per year, until adolescence (Wong 1999). There is little doubt that installation also contributes to high rates of misuse of child restraint systems because of the wide variety of safety seat models, seat belt systems, and seating configurations in vehicle interiors. Some of the most common difficulties with restraint installation are ensuring tightness of harness straps and safety belts and remembering to use locking clips or tether straps (Kohn et al. 2000; Lane et al. 2002).

However, the challenges that parents face in making vehicle safety decisions also depend on the accuracy and availability of the information that supports the effective use of restraint systems. The accuracy of information on the correct installation of safety seats varies, depending on the manufacturer's instructions, the directions of sales personnel, and the advice of family or friends. It is estimated that only 50% of parents actually read the product manual on how to install the safety seat properly. For those who do, the instruction manual’s vocabulary often exceeds the parent’s comprehension level (ability to readily understand the information and follow the directions for proper utilization) (Block et al. 1998; Decina and Knoebel 1997; Gaines et al. 1996; Wegner and Girasek 2003). In a recent study of 107 manuals from 11 different manufacturers, a grade 10 reading level was required, on average, in order to fully comprehend the information presented (Huggins 2003).

Nonuse is another significant issue. The rationales that parents describe for choosing not to use a child safety restraint for their toddlers or preschool children include the child’s fussiness and discomfort, the inconvenience of using the device, and the need for using a restraint device for a younger child (Decina and Knoebel 1997).

Intervention Research

A systematic review of interventions designed to increase use of child safety seats was conducted in 2001 (Zaza et al. 2001). The review focused on the effectiveness of five interventions aimed at increasing child safety seat use. The success of each intervention was evaluated in terms of changes in the use of child safety seats or injury rates. At the time of the review in 1998, more than 3,500 citations were screened, and 72 met the inclusion criteria for the reviews. The results of this review identified “strong evidence of effectiveness for child safety seat legislation and distribution plus education programs” (Zaza et al. 2001, page 31). Education-only programs directed toward parents, young children, health care professionals, or law enforcement personnel (Zaza et al. 2001, page 31) were found to be less effective than communitywide information/enhanced enforcement campaigns and incentive-plus-education programs.

In 1999, Rivara identified the need for intervention research to investigate methods to increase the use of booster seats. It was suggested that different strategies might be needed for this older population than what had been previously used for younger children. Knowledge of the benefits and purpose of booster seats alone is not sufficient to promote increased use (Simpson et al. 2002). Parental perception of risk, awareness/knowledge, and parenting style were identified as issues affecting use when comparing parents of children in booster seats with those who had put their children into seat belts. In this study, media campaigns, improved laws, education for parents, and extending the use of child restraints to older children were among the strategies suggested by parents in focus groups for increased use of booster seats.

Ebel et al. (2003) conducted a prospective, nonrandomized, controlled community intervention trial to evaluate the effectiveness of a multi-faceted community booster seat campaign designed to increase observed booster seat use among child passengers in motor vehicles. By 15 months after the start of the campaign, booster seat use did increase significantly in the intervention communities relative to the control communities. The success of this intervention was in part due to the multi-faceted approach that was undertaken.

Agent-based Modeling Systems

Multi-agent-based interoperation is a new paradigm distinguished by features such as requests that are specified in terms of “what” and not “how”; agents that can take an active role, monitoring conditions in their environment and reacting accordingly; and agents that may be seen as holding beliefs about the world (Huhns and Singh 1997).

Agent-based modeling is gaining popularity because of its versatility for encapsulating and abstracting complex system models. Furthermore, its application has evolved beyond the discipline of computational and computer science, and it has been adopted in a variety of disciplines ranging from administration and economics to health care and policy making.

In this study, an agent-based simulation is developed to analysis the child safety issues in North American societies. Various statistical analyses and surveys have been adopted into the model in order to initialize it and provide a realistic perspective on various agent functions. Child safety issues depend on a variety of social, mental, and emotional factors, and traditional surveys and statistical analyses, because of their multi-dimensional nature, fall short in discovering emerging aspects of these issues under dynamic conditions. For instance, the perspective that parents have and choices that parents make about their children’s safety depend on their knowledge about this issue, personal way of thinking, ethnic background, cultural influences, financial position, and enforced laws, along with observed and learned experiences.

Repast (Recursive Porous Agent Simulation Toolkit) is an open source tool for developing agent-based simulations created at The University of Chicago and maintained by Argonne National Laboratory (ANL). It is especially suitable for implementing a simulation model that involves living social entities or beings. Repast provides an excellent framework and specifications for developing agent-based simulations. The framework’s support is not limited to core simulation strategies (like event scheduling and random number generation), intuitive user interface, and graphic generation and visualization tools; it also provides built-in support for genetic algorithms, neural networks, and geographic information systems (GISs). Since it is open source and distributed under the GNU general public license (GPL), the user can customize and extend it virtually in any way he or she chooses. Currently, Repast is available in three flavors: Repast J for the Java platform, Repast .Net for Microsoft .Net framework, and Repast Py for Python scripting. In this prototype, we used Repast J 3.0 in order to fully exploit the flexibility of Repast and the portability of Java (Xu 2004).

MODEL DESIGN AND IMPLEMENTATION

An agent in the current model is designed as a household consisting of individual members, including their gender, age, and kinship status, as well as information about the household’s income level and other relevant ethnic and social characteristics. Household members can be adult individuals, including parents, and children. Associated with each household is a set of vehicles. A driver is a designated individual who satisfies the rules, such as age and license issue. The event of driving is abstracted by the class Trip. In the AutoSimModel, the creation of the agents and initiation of the events in the model along with various probes may be implemented. The class diagram, representative of the basic classes in the object-oriented Repast model, is illustrated in Figure 2.

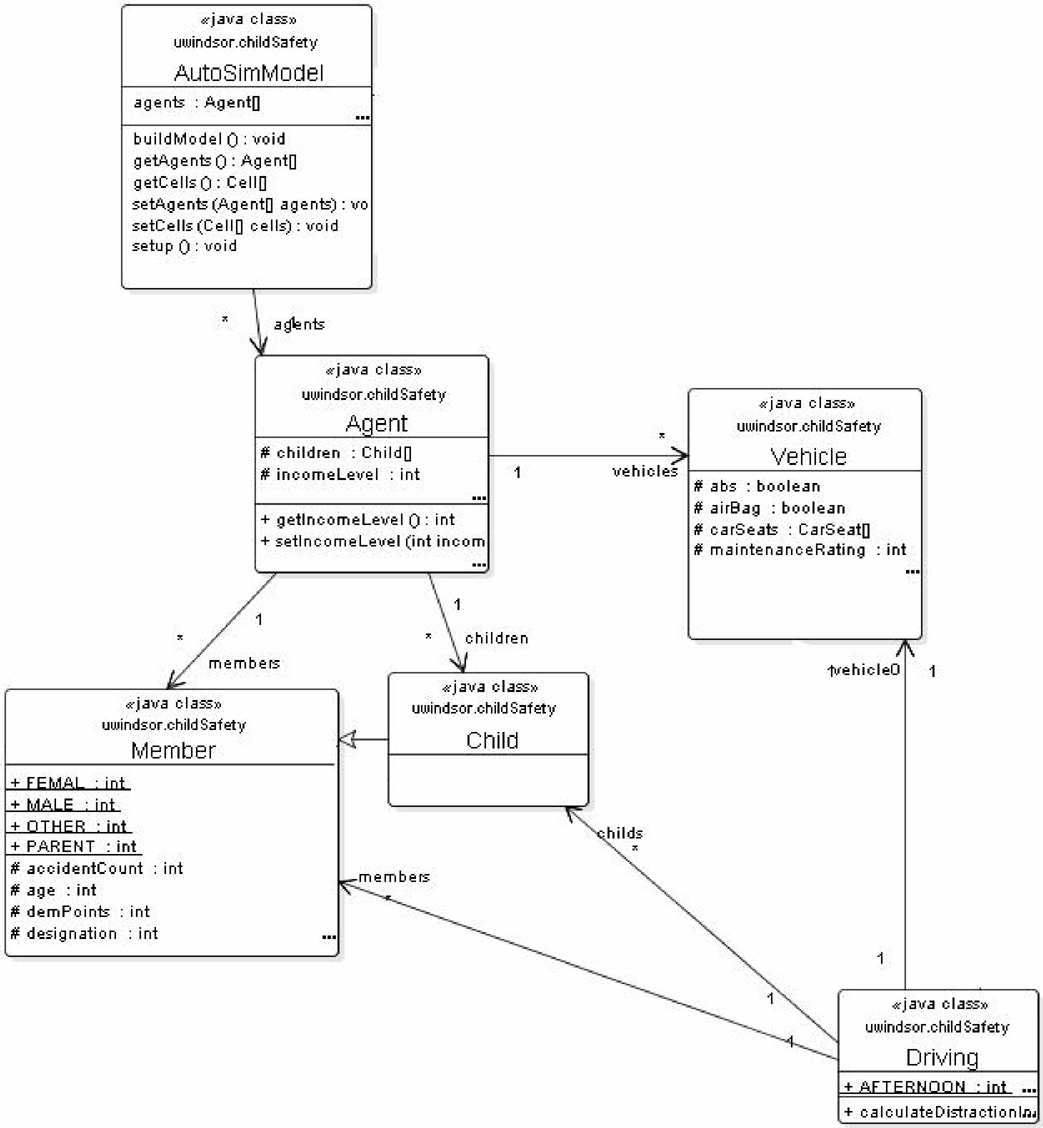

FIGURE 2 Class diagram: Java package uwindsor.childSafety

Indices and Functions

To initialize the model data and functional behavior, we rely on known measures and outcomes for common procedures. Specifically, we use empirical indices to identify the states of each event. A number of indices that have been formulated are described below.

The probability of a driver to become involved in an accident mostly depends on his/her personal driving experience, the condition of the vehicle, the traffic conditions at the time of driving, the trip distance and duration, and some other factors that may cause distraction while driving. In order to estimate the probability of an accident, we consider three indices: driver's experience index (DEI), distraction index (DI), and vehicle safety index (VSI). Each of these indices assumes a value in the closed range 1 to 10, with the possibility of a value of 0 indicating the absence of influence from such index. These indices are employed in the probability of accident index ($P_{Accident}$) by using the following rule:

$$P_{Accident} = (DEI \times W_{DEI} + DI \times W_{DI} + VSI \times W_{VSI})/100, \quad (1)$$

where W_{DEI}, W_{DI}, and W_{VSI} correspond to the weight percentage for each of the DEI, DI, and VSI indices, respectively. The weight is an estimated measure for the effect that a given index has on the overall circumstances for the likelihood of an accident. If the weights are not known, they are assumed to be divided equally for each of the indices. Note that the value of $P_{Accident}$ is bounded to assume a value in the closed range [1–10]. In the current prototype, we kept all the weights equal. Consequently, Equation 1 reduces as follows:

$$P_{Accident} = (DEI + DI + VSI)/3. \quad (2)$$

Table 1 summarizes all the factors currently considered in calculating each of these indices.

The model assumes that a higher value for $P_{Accident}$ indicates increased chances for an accident to take place, and a lower value reduces the likelihood of an accident (an indicator of safer driving conditions). In Equation 2, $P_{Accident}$ is directly proportional to the individual values and the chances for an accident. Hence, the following observations are implied:

1. A higher DEI value indicates a risky driver, and a lower value indicates a safer driver.

2. A higher DI means a higher distraction level, and a lower DI implies the opposite.

3. A higher VSI means the vehicle is more prone to an accident, and a lower VSI means the opposite.

TABLE 1 Indices used in the simulation

Index	Factors Considered	Comment
Driver's experience index (DEI)	Years of experience, age , sex, training, ethnicity, birthplace, years living in Canada, education level	Can assume a value of 1 to 10, with lower values indicating safer driver
Distraction index (DI)	Passenger's average age, time of day, traffic condition, road rage, cell phone usage	Can assume a value of 1 to 10, with lower values indicating lower level of distraction
Vehicle safety index (VSI)	Model, year, mileage	Can assume a value of 1 to 10, with lower values indicating safer car
Probability of accident index	Driver's experience index, distraction index, vehicle safety index	Can assume a value of 1 to 10, with lower values indicating lower chance of an accident

The value of DEI (Table 2) is calculated by using the following rule (Equation 3), again scaled to the range 1 to 10:

$$\begin{aligned} DEI = {} & W_{yearsOfExperience} \times yearsOfExperience + W_{age} \times age \\ & + W_{sex} \times sex + W_{training} \times training + W_{ethnicity} \times ethnicity \\ & + W_{educationLevel} \times educationLevel + W_{birthPlace} \times birthPlace \\ & + W_{yearsLivingInCanada} \times yearsLivingInCanada. \end{aligned} \tag{3}$$

In the current implementation of Equation 3, the weights are as shown in Equation 4:

$$\begin{aligned} DEI = {} & 0.25 \times yearsOfExperience + 0.25 \times age \\ & + 0.05 \times sex + 0.10 \times training + 0.05 \times ethnicity \\ & + 0.10 \times educationLevel + 0.10 \times birthPlace \\ & + 0.10 \times yearsLivingInCanada. \end{aligned} \tag{4}$$

The DI encapsulates the major relevant factors that may contribute to driver distraction while driving, consequently leading to reduced driving performance and an increased likelihood of an accident. Table 3 shows the calculation details for this method. Each of the factors again assumes a value 1 to 10, with 1 being the lowest level of distraction and 10 being the highest.

Equation 5 details the computation of DI; the equation is simplified since the weights are equal in this case.

$$\begin{aligned} DI = {} & (AgeIndex + RoadRageIndex + TrafficIndex \\ & + TimeOfDayIndex + CellPhoneIndex)/5. \end{aligned} \tag{5}$$

Some vehicle models have improved safety over others. The model, age, and mileage of the car are the main indicators that reflect the capability of the vehicle to sustain accidents. The VSI represents the overall contribution of the vehicle choice in an accident scene. Each of the factors in Table 4 assumes a value of 1 to 10, with 10 being the worst and 1 being the best choice for a vehicle in terms of safety.

Equation 6 shows the computation of VSI:

$$\begin{aligned} VSI = {} & (W_{type} \times TypeIndex + W_{age} \times AgeIndex \\ & + W_{mileage} \times MileageIndex)/100. \end{aligned} \tag{6}$$

The vehicle selection function is used at the very beginning of the simulation in order to initialize each agent (or household) with a set of vehicles. Its rules are based on Table 5 to assign a vehicle to a household depending on its income level and family size.

In order for the model to establish a frame of reference for the correct selection for the child restrain, we identify in Figure 3 the proper selection procedure for seat usage depending on the child’s age and height. In the model, we are now able to compare the driver’s actual decision to the correct one.

TABLE 2 Driver experience index calculation table

Factor (Variable Name)	Description/Rule	Weight (%)
Years of experience	YearExp < 5 ⇒ 10.0 YearExp < 10 ⇒ 9.0 YearExp < 15 ⇒ 7.0 YearExp > 15 ⇒ 4.0	25
Age	Age < 18 or Age > 80 ⇒ 10.0 Age < 20 or Age > 75 ⇒ 9.0 Age < 25 or Age > 70 ⇒ 7.0 Age < 30 or Age > 60 ⇒ 6.0 Age < 35 or Age > 50 ⇒ 5.0 Age < 40 or Age > 45 ⇒ 4.0 Age ≤ 45 or Age ≥ 40 ⇒ 3.0	25
Sex	Sex = male ⇒ 9.0 Sex = female ⇒ 7.0	05
Training	Country of driver's training: Canada ⇒ 5.0 USA ⇒ 8.0 Others ⇒ 9.0	10
Ethnicity	Caucasian ⇒ 6.0 Native ⇒ 6.0 Asian ⇒ 7.0 African ⇒ 7.0 European ⇒ 7.0 Others ⇒ 9.0	05
Education level	Below high school ⇒ 9.0 High school graduate ⇒ 7.0 College graduate or higher ⇒ 5.0	10
Birthplace	Canada ⇒ 6.0 USA ⇒ 8.0 Other ⇒ 9.0	10
Years living in Canada	< 5 years ⇒ 8.0 < 10 years ⇒ 7.0 < 15 years ⇒ 4.0 < 20 years ⇒ 2.0	10

TABLE 3 Distraction index calculation table

Factor (Variable Name)	Description/Rule	Weight (%)
Passenger's age group (average age)	Average age < 15 ⇒ 10.0 Average age < 20 ⇒ 9.0 Average age < 25 ⇒ 8.0 Average age > 30 ⇒ 7.0 Average age > 35 ⇒ 6.0 Average age > 40 ⇒ 5.0 Average age > 45 ⇒ 4.0 Average age > 50 ⇒ 3.0 Average age > 55 ⇒ 1.0	20
Road rage	Involved ⇒ 10.0 Not involved ⇒ 00.0	20
Traffic conditions	Rush hour ⇒ 9.0 Busy ⇒ 8.0 Moderate ⇒ 7.0 Light ⇒ 6.0 Very light ⇒ 5.0	20
Time of day	Morning ⇒ 9.0 Noon ⇒ 7.0 Afternoon ⇒ 8.0 Evening ⇒ 6.0 Night ⇒ 4.0	20
Cell phone usage	Using ⇒ 9.0 Not using ⇒ 0.0	20

The current simulation is specially designed to work with a comparable demographic pattern as experienced in the Auto 21 survey literature. When initializing the agents, it uses the known statistics, such as the age group distribution of the adult population, average size of households, and average number of children per family. Some other statistics are also used from other sources detailed in the model for each specific parameter. Initially, the model distributes the vehicle objects among the households by using the vehicle selection function (Table 5). Indices like DEI and VSI are also calculated at this time. The DI is calculated at simulation time. The sequence of operations to initialize the model is depicted in Figure 4.

Each time-step in the simulation is equivalent to a day in the life of an agent. The simulation starts by scheduling each driver's driving assignments; it is, of course, possible for a driver not to drive on a given day. While selecting a household for driving, some statistics were used from the survey literature (e.g., 66% of parents drive their children on an everyday basis). The DI and probability of accident index ($P_{Accident}$) are calculated at this point. Depending on the $P_{Accident}$ values, some of the trips become involved in an accident. After an accident occurs,

TABLE 4 Vehicle safety index calculation table

Factor (Variable Name)	Description/Rule	Weight (Total 100%)
Model/type	SUV ⇒ 9.0 Mini van ⇒ 7.0 Van ⇒ 6.0 Truck ⇒ 6.0 Coupe ⇒ 6.0 Sedan ⇒ 4.0 Station wagon ⇒ 5.0	$W_{type} = 20$
Age = current year – model year	Less than 1 year old ⇒ 2.0 Less than 2 years old ⇒ 3.0 Less than 4 years old ⇒ 4.0 Less than 6 years old ⇒ 5.0 Less than 8 years old ⇒ 6.0 Less than 10 years old ⇒ 7.0 Less than 12 years old ⇒ 8.0 Less than 14 years old ⇒ 10.0	$W_{age} = 40$
Mileage	Less than 50,000 km ⇒ 2 Less than 100,000 km ⇒ 3 Less than 150,000 km ⇒ 5 Less than 200,000 km ⇒ 6 Less than 220,000 km ⇒ 7 Less than 250,000 km ⇒ 8 Less than 300,000 km ⇒ 9 More than 300,000 km ⇒ 10	$W_{mileage} = 40$

the health indices of the involved persons are consequently updated, along with the vehicle damage. The output graphs and charts probing the model are updated every 50 steps. The main operations and the life cycle of an agent are depicted in Figures 5 and 6, respectively.

The simulation is executed for 365 time-steps (days), and the results summarizing demographic distribution, correctness of child car seat usage, and average health over time are presented. The demographic distribution histogram shown in Figure 7 is generated right after the simulation is initialized, and it is scheduled for an update every 365 ticks (1 year). The height of the bars represents the frequency of each age group. Most likely drivers are in the age range of 31 to 36 years.

Figure 8 shows the correct child seat usage for each of the child age groups: infant (1−12 months), toddler (13–48 months), and walker (49–144 months). This graph is updated every 50 ticks (days). If there is no legislation in effect, drivers do not learn the correct child seat usage, and subsequently this graph remains almost the same over time in the current simulation.

TABLE 5 Vehicle selection function based on family size and household income[a]

Family Size (No. of Members)	Household Income ($ per Annum)						
	Below 20 K	Below 30 K	Below 40 K	Below 60 K	Below 80 K	Below 100 K	Over 100 K
1	0 or 1 sedan 9-12	1 or 2 sedan/van 7-10	1 or 2 any type 5-8	1 or 2 any type 4-7	1 or 2 any type 2-5	1 or 2 any type 0-3	1 or 2 any type 0-3
2	0 or 1 sedan 9-12	1 or 2 sedan/van 7-10	1 or 2 sedan/van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3
3	0 or 1 sedan 9-12	1 or 2 sedan/van 7-10	2 or 3 sedan /van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3
4	0 or 1 sedan 9-12	1 or 2 sedan/van 7-10	2 or 3 sedan /van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3
5	0 or 1 sedan /van 9-12	1 or 2 sedan/van 7-10	2 or 3 sedan /van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3
6	0 or 1 sedan /van 9-12	1 or 2 sedan/van 7-10	2 or 3 sedan /van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3
7 or more	0 or 1 sedan /van 9-12	1 or 2 sedan/van 7-10	2 or 3 sedan /van 5-8	2 or 3 any type 4-7	2 or 3 any type 2-5	2 or 3 any type 0-3	2 or 3 any type 0-3

[a] In each cell, the first line is the number of vehicles the family may have. The second line is the type of vehicles the household may own, and the third line indicates how many model years old the vehicle may be.

Figure 9 shows the correct and incorrect seat usage comparison among different weight groups of school-aged children. The figure shows a snapshot of the graph at the very beginning of the simulation. This graph shows no change over time if there is no legislation or change in driver knowledge about child safety. Should there exist any such characteristics of learning or enforcement, the outcome would change. We would expect an increase in the correct usage frequency and a decrease in the incorrect usage.

The overall measure of the effectiveness of proper seat usage and increase in safety is revealed in Figure 10, which shows the average health of adults and children over time. The health index is based on a normalized value from 0 to 10, where the higher the number means the healthier the individual. This value is normalized to reflect the level of injury sustained by individuals after an accident. A recovery period can be implemented to enable improvement in

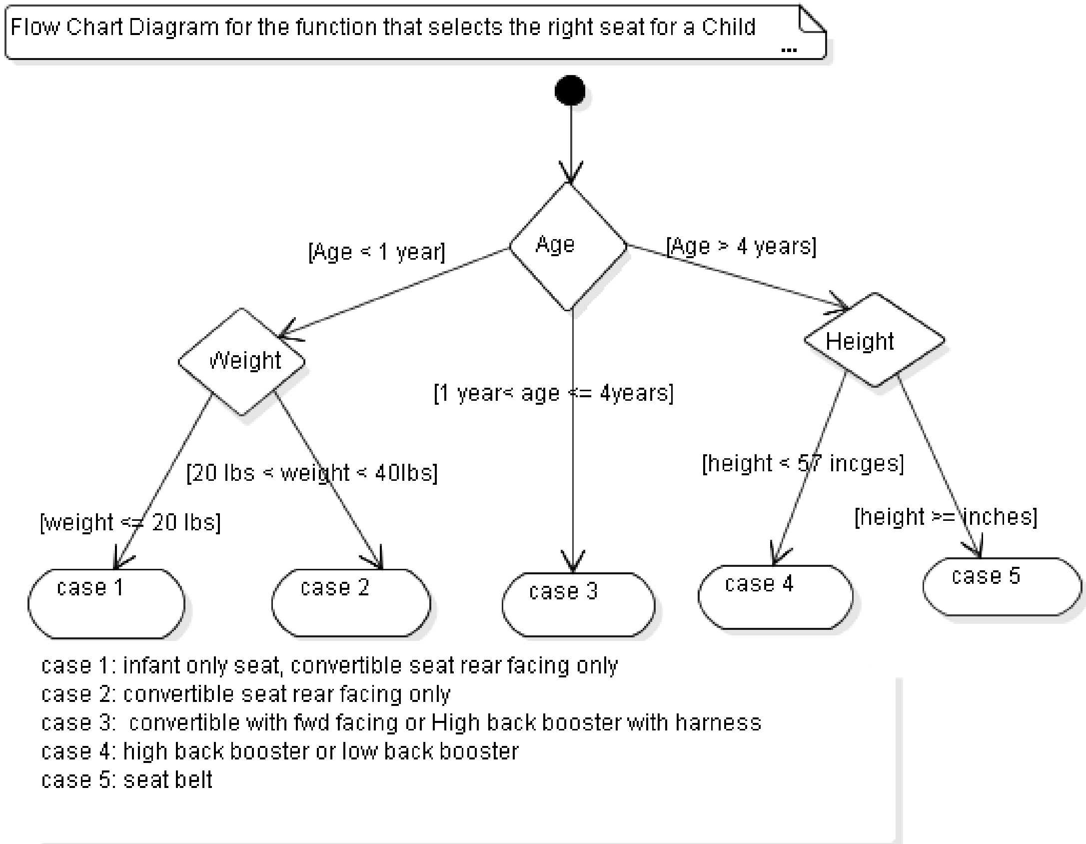

FIGURE 3 Flow chart for the method that assigns a child correctly to a seat on the basis of his/her age, weight, and height

health over time (i.e., healing). Some injuries, however, are terminal, which is indicated by lower values, and death is when an individual reaches a health index of 0; subsequently, the dead individual is removed from the system.

CONCLUSIONS AND FUTURE WORK

This paper presents a new approach for studying vehicle injury prevention for the general population and for children in particular. The first phase of the study is to build a prototype capable of modeling agent behavior, including vehicle selection, driver assignment, child seat usage, and accident generation. Many parameters were used to initialize the model; they were based on published studies and field surveys. Different measures were then implemented to probe the outcome of the system. Some histograms can reveal insights about the population being modeled and thereby enable us to understand the characteristics of the population and various demographic aspects, such as age and gender distributions of drivers. Other graphs can measure the levels of correctness of child seat use, indicative of the knowledge of the drivers in the modeled system. Furthermore, we can examine the overall population health, even breaking it down to adult and child health separately, in order to see the effect of learning, prevention, or legislation on the driver behavior and overall injury levels in the population over time.

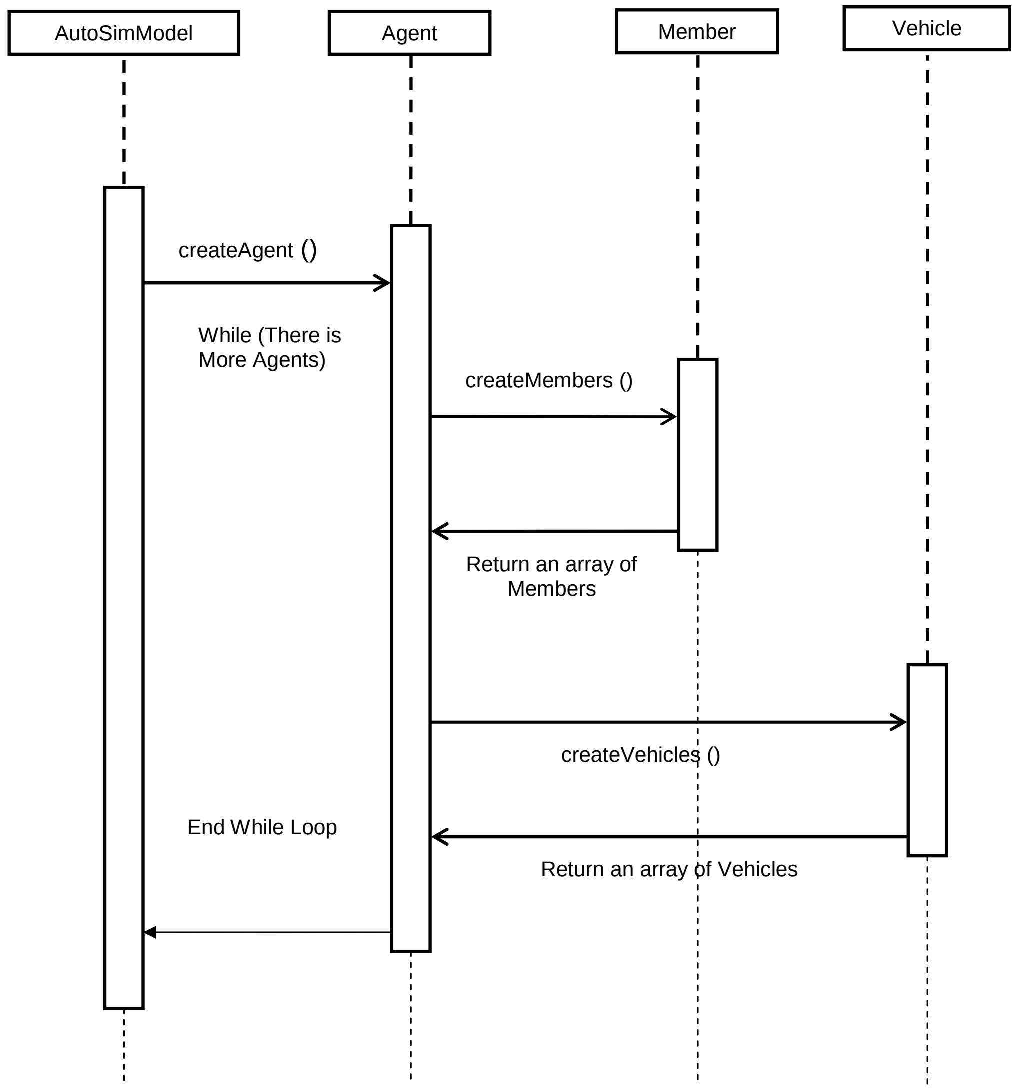

FIGURE 4 Model initialization sequence diagram

In the current prototype, we enable the agents to behave in a probabilistic, nearly deterministic manner. The next phase of work will involve the addition of the ability of agents to learn and adapt to various injections and feedbacks in the model. For instance, given an enforceable legislation, a driver who receives a fine for incorrect use of a seat for a child would make the driver learn from his/her mistake and make the correction in the future, thereby reducing the injury level in the case of an accident. Other parameters can also be added into the system, and additional measures can be probed in order to validate the system.

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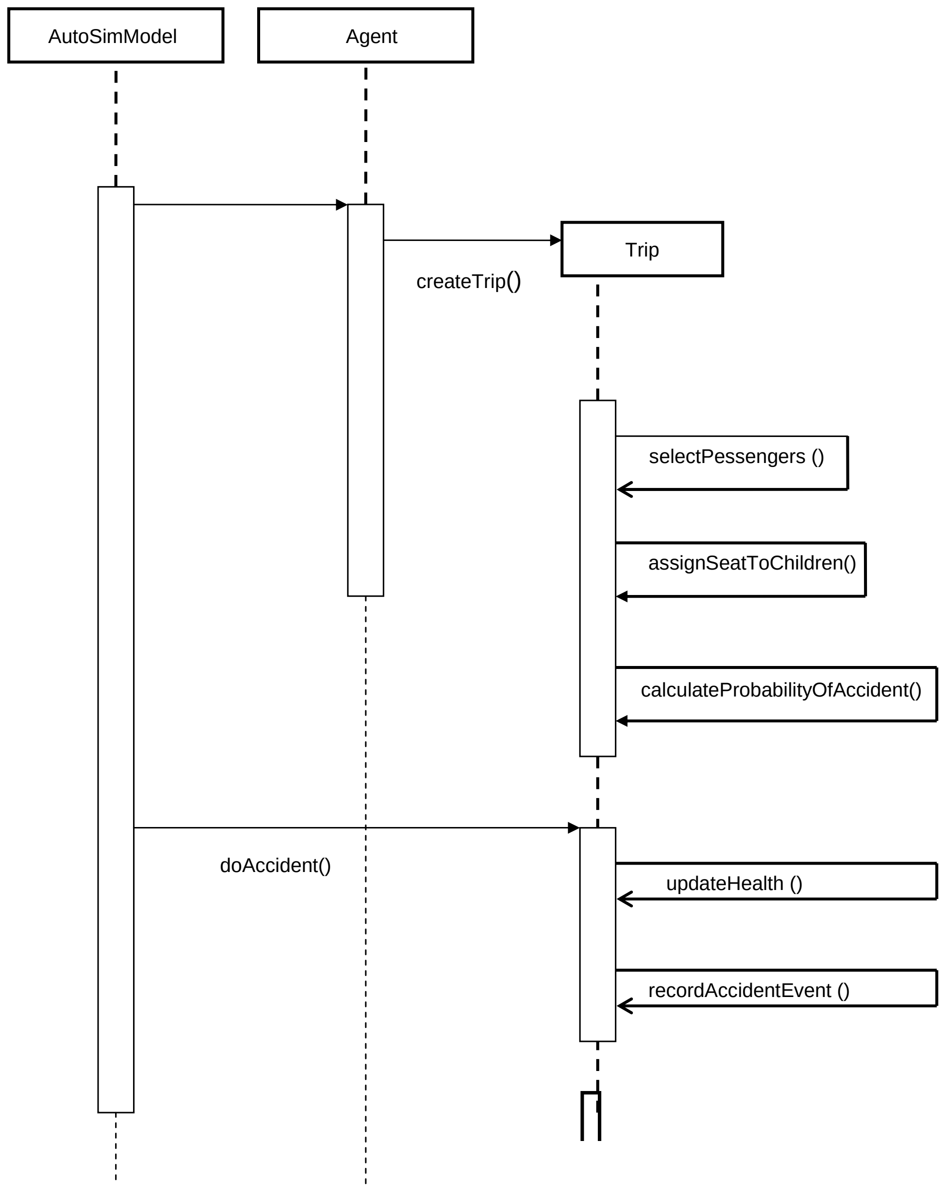

FIGURE 5 Summary of agent actions in a single time-step

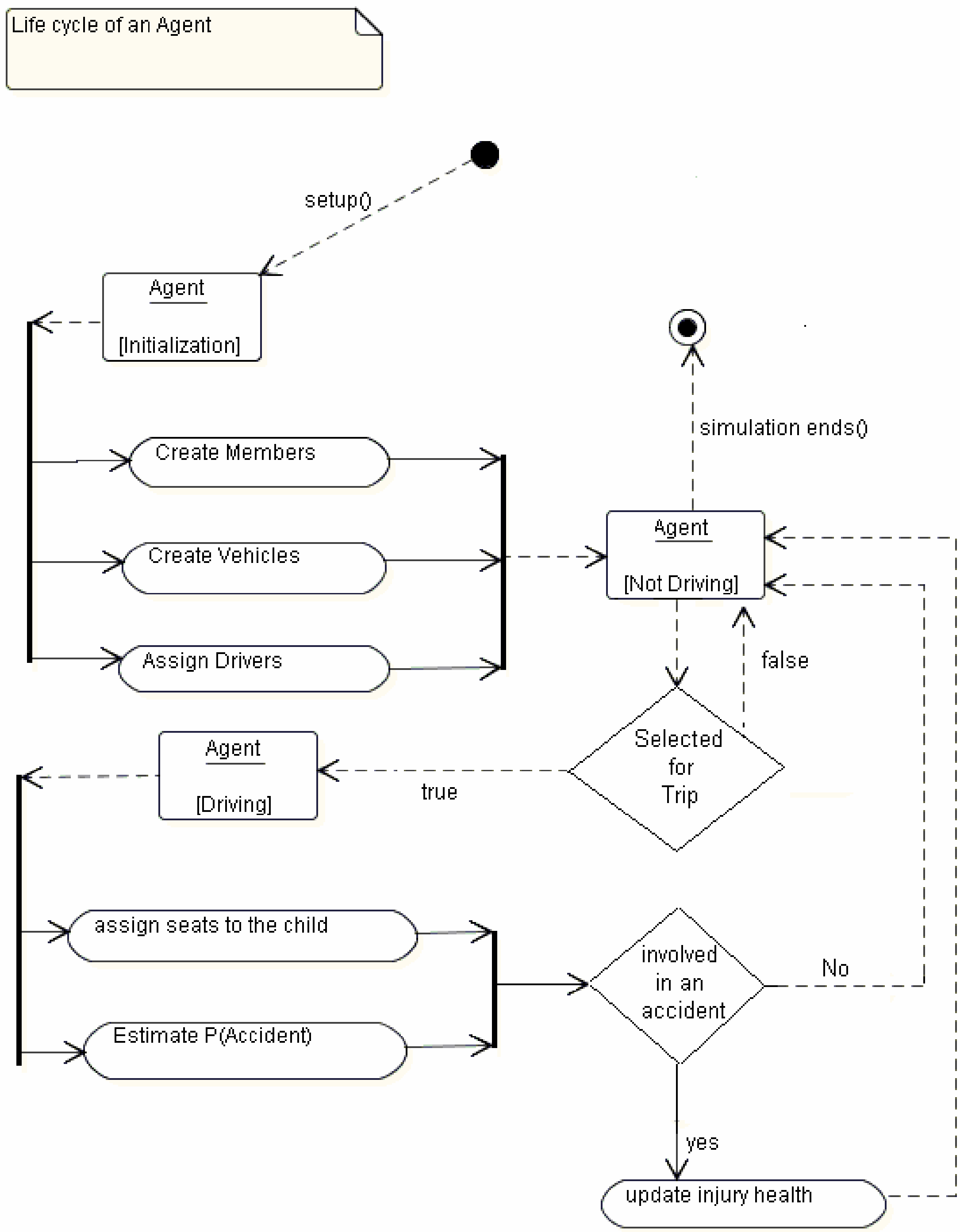

FIGURE 6 Life cycle of an agent through the entire run of the simulation

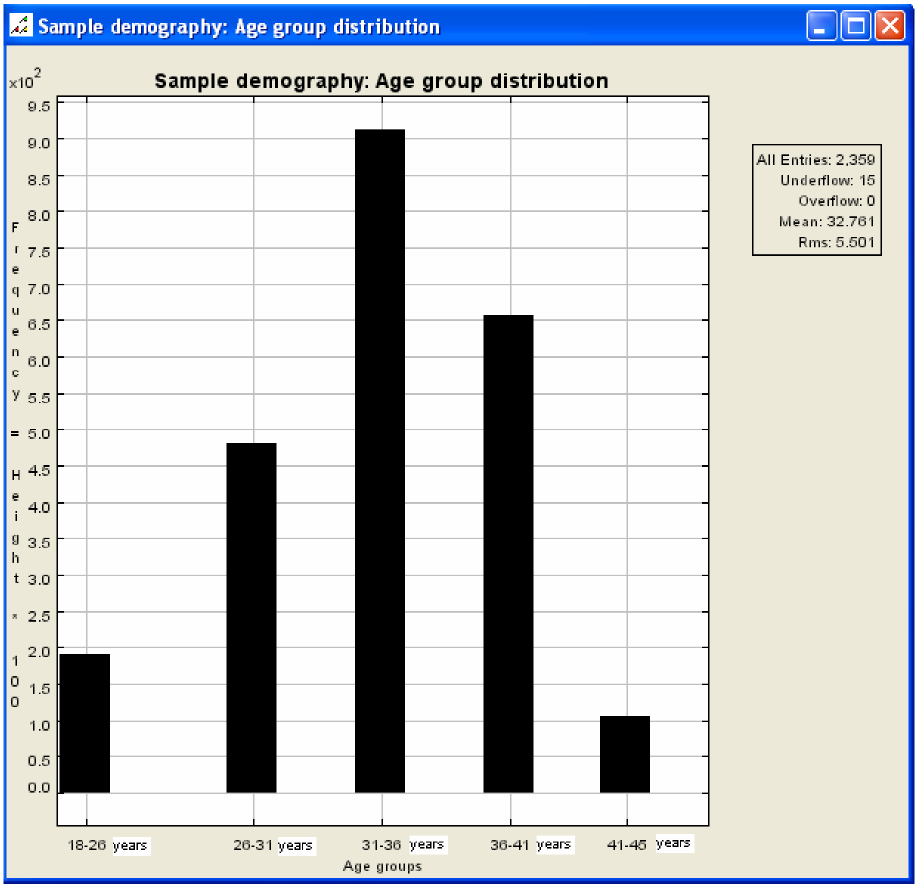

FIGURE 7 Age distribution of the adult population (Age groups are on the x axis, and frequencies are on the y axis, where frequency = height × 100.)

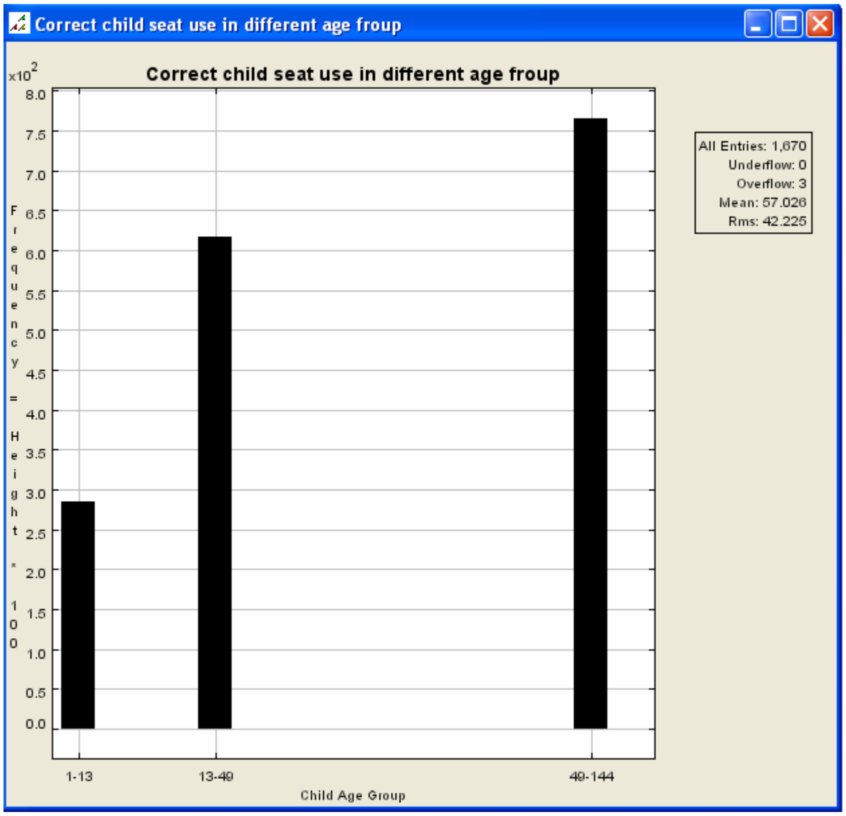

FIGURE 8 Correct seat usage distribution among all children (Among 1,900 children, approximately 290 infants, 620 toddlers, and 760 school-aged children use the correct seat; the rest use incorrect seats.)

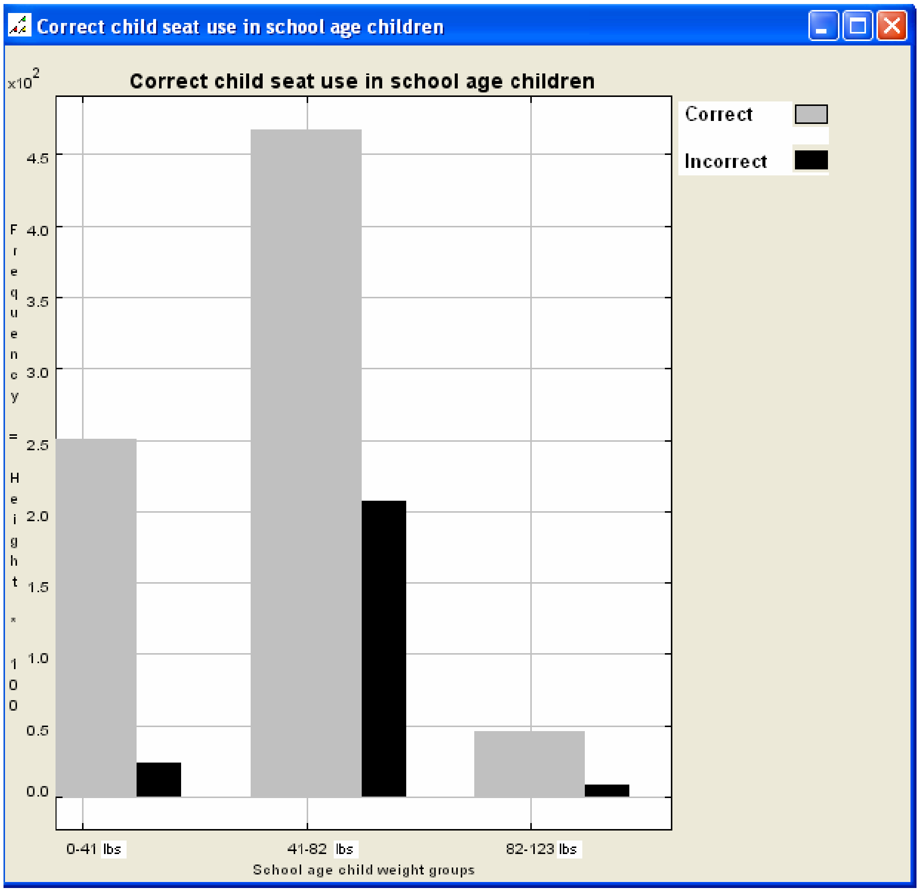

FIGURE 9 Correct vs. incorrect seat usage among different weight groups of school-aged children

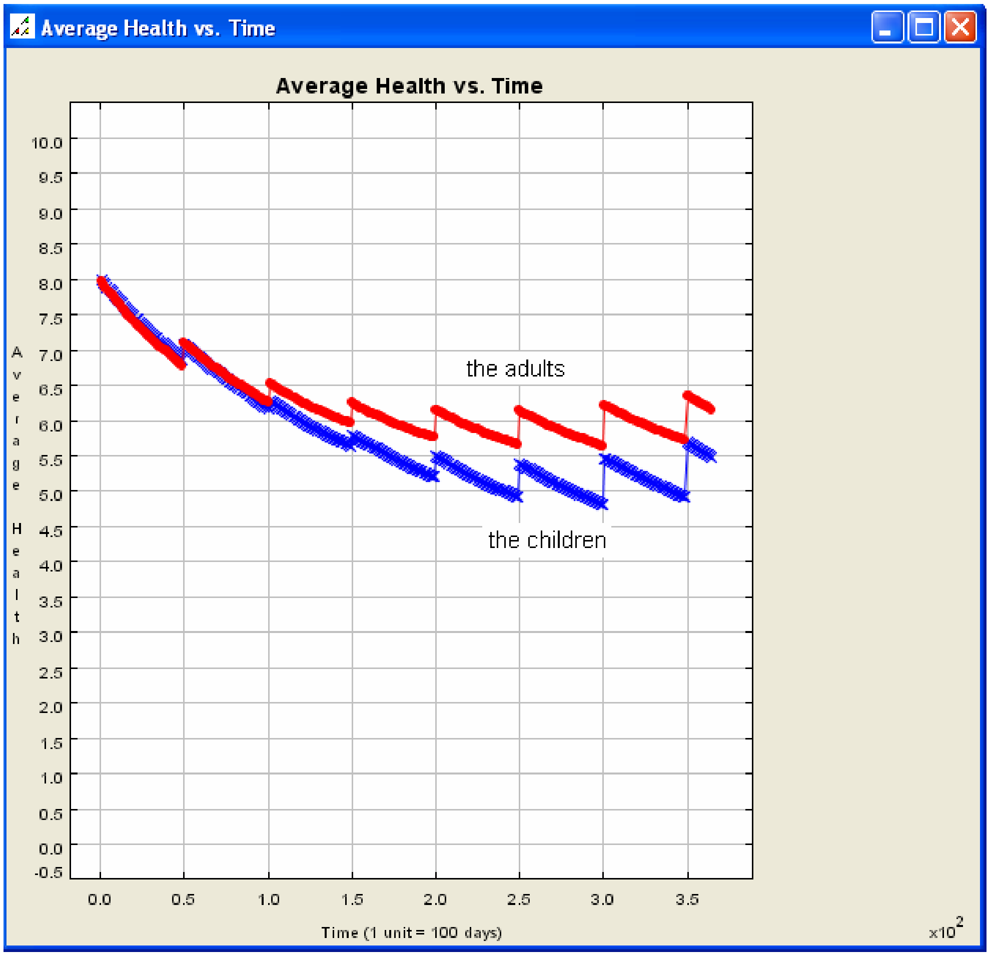

FIGURE 10 Average health index for adults and children over time

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